


COMMENTARY

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Simulating social-ecological systems: the Island Digital Ecosystem Avatars (IDEA) consortium

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Abstract

Systems biology promises to revolutionize medicine, yet human wellbeing is also inherently linked to healthy societies and environments (sustainability). The IDEA Consortium is a systems ecology open science initiative to conduct the basic scientific research needed to build use-oriented simulations (avatars) of entire social-ecological systems. Islands are the most scientifically tractable places for these studies and we begin with one of the best known: Moorea, French Polynesia. The Moorea IDEA will be a sustainability simulator modeling links and feedbacks between climate, environment, biodiversity, and human activities across a coupled marine–terrestrial landscape. As a model system, the resulting knowledge and tools will improve our ability to predict human and natural change on Moorea and elsewhere at scales relevant to management/conservation actions.

Keywords: Computational ecology, Biodiversity, Genomics, Biocode, Earth observations, Social-ecological system, Ecosystem dynamics, Climate change scenarios, Predictive modeling

Background

High-throughput data collection techniques and large-scale computing are transforming our understanding of ecosystems, making convergent scientific frameworks a research priority [1]. As human activities increasingly impact ecosystem processes, we need new approaches that focus on how whole communities of organisms interact with people and the physical environment at the scale of landscapes or catchments [2]. This requires an e-infrastructure for data intensive science that enables the integration of computational physics, chemistry, biology, ecology, economics and other social sciences.

Such an advance would allow researchers to (1) characterize the multidisciplinary functional attributes of social-ecological systems; (2) quantify the relationships between those functional attributes under historic and current conditions; and (3) model the trajectories of goods and services under a range of policy-driven scenarios and future environmental conditions. The resulting knowledge would improve our ability to predict human and natural change at scales relevant to management/conservation actions.

Unlike some aspects of climate change, processes related to biodiversity and ecosystem services are “typically place-based and many of the effects are seen at sub-global scales” [3]. Inspired by successes in modeling complex systems at other scales of organization, notably the cell [4], the Island Digital Ecosystem Avatars (IDEA) Consortium aims to build computer simulations (‘avatars’)

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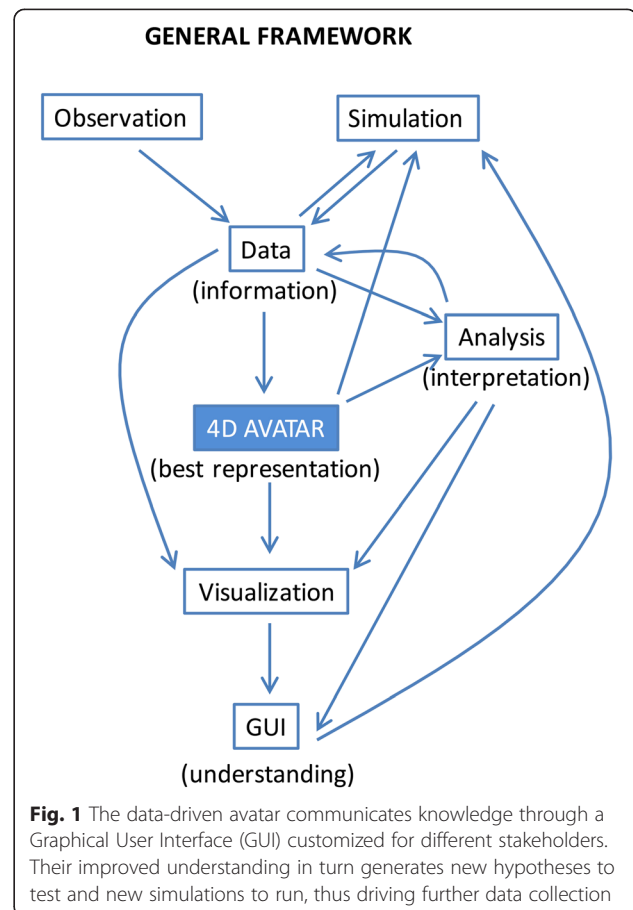
to the scale of whole social-ecological systems. With a common boundary constraining their physical, ecological, and social networks, islands have long been recognized as model systems for ecology and evolution [5]. Their geography sets clear limits on the species to inventory, space holders (ground cover) to measure, organisms to count, physical–chemical contexts to characterize, and natural–human interactions to consider. The knowledge and cyberinfrastructure developed for island avatars, and complementary efforts targeting major cities like Singapore [6] and New York [7], will eventually scale to countries and regions, including their associated coastal waters. Island avatars are built from the genome up, while at the same time downscaling regional models to establish boundary conditions. They address many of the challenges faced by macrosystems ecology [8], and general ecosystem models [9]. Indeed, an Earth Avatar would converge on the Global Earth Observation System of Systems (GEOSS) [10] and Future Earth [11]. The IDEA approach, however, avoids overwhelming complexity, instead concentrating effort on the simplest social–ecological systems that include most of the data types covered by GEOSS, and many of the processes found globally.

Moorea IDEA

The small island of Moorea (134 km²) in French Polynesia is well placed for a proof-of-concept study. About 15 km northwest of Tahiti with a population of ~17,000, Moorea is perhaps the best studied island in the world [12] thanks to several decades of activity at its two research stations (CNRS-EPHE CRILOBE [13], and the University of California (UC) Berkeley Gump Station [14]), which respectively house France's Center of Excellence for Coral Reef Research (LabEx CORAIL [15]), and the US National Science Foundation's only coral reef Long-Term Ecological Research (MCR LTER) site [16], which is administered by UC Santa Barbara. Additionally, the Moorea Biocode Project [17] has characterized every species (>1 mm) on the island, including genetic sequences, museum specimens, and digital photographs [18]. While there is still much more to learn, especially concerning the vastly diverse microbes [19] and human systems, the existing physical and biotic databases provide a powerful foundation for whole system ecological modeling. Combined with a wealth of data on the resilience of Moorea's ecosystems, including the response of its coral reefs to large-scale perturbations [20] and the evolution of Polynesian society [21], Moorea has many of the characteristics needed to advance systems ecology and sustainability science [22].

The Moorea IDEA aims to understand how biodiversity, ecosystem services, and society will co-evolve over the next several decades depending upon what actions are taken. Specifically, we ask: (1) what is the physical,

biological, and social state of the island system today? (2) How did it get to this point? (3) What is its future under alternative scenarios of environmental change and human activity, including conservation efforts? These questions are addressed through a place-based data science infrastructure and computational platform (Fig. 1). The Moorea Avatar is the best digital representation of the island; a three-dimensional visualization of Moorea that looks similar to the one on Google Earth, but which includes the dimension of time and enables researchers to zoom into a location, access data, and run simulations. Today's island represents the key baseline because the majority of the modeling data needed are not available for historic time periods. The Avatar computational platform allows other versions of Moorea to be generated and visualized *in silico* for a range of purposes. This involves the integration of physical, biological, and social data [12–21], and drawing on best-available scientific knowledge to show what the island looked like in the past (using historic baselines to explore particular issues), and to predict how it might look in the future. Unlike video games, our projections are constrained by reality and are intended not only for research and education, but also to support scenario-based planning; helping



local communities adapt to environmental change and maximize ecological resilience. Our goal is to emulate P4 Medicine, extending to social–ecological–physical systems the Predictive, Preventive, Personalized, and Participatory approach that promises to revolutionize the biomedical field [23].

Working with the local population to co-develop island avatars as “boundary objects” [24] is critical to ensuring that the simulations are useful, credible and legitimate. Non-scientist stakeholders take joint ownership of their avatar by prioritizing the policies to simulate (e.g., conservation plans), and by contributing traditional/local knowledge and data. The participatory approach includes citizen science, taking advantage of newly affordable technologies and helping reconnect people with natural processes through observation and experiential learning.

Organization

The Moorea IDEA was initiated by researchers associated with the UC Berkeley Gump Research Station and CRIOBE, through a workshop at the Pauli Center for Theoretical Studies, ETH Zurich, in November 2013. The Consortium now includes more than 80 scientists from around the world, representing the physical, biological, social, computer and information sciences. Institutional nodes (more than 20) form its governing body, which is currently led by an Executive Committee representing the founding institutions. The Consortium addresses convergent research questions across areas of societal interest (energy, water, nutrients, biodiversity, food and nutrition, and health) through five overlapping and interlinked working groups (Table 1). The Moorea IDEA has gained support from the Municipality of Moorea and the territorial government of French Polynesia. In the future, other islands could join to form a network that shares the generally applicable tools and approaches generated by the IDEA Consortium. For example, the nearby atoll Tetiaroa constitutes a worthwhile comparison to Moorea. Further afield, and reflecting the ambition to scale to larger places,

scientists and government officials from Crete have expressed a strong interest in the project.

Conclusions

The new Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) has prioritized an assessment on the “Modeling of Biodiversity and Ecosystem Services” [25]. Addressing this grand challenge will require computational models of place that are able to simulate alternative scenarios and visualize likely outcomes for scientists, policymakers, and the public [26]. Big data, computational ecology, and sophisticated simulation platforms cannot solve all of the world’s problems, but harnessing scalable technology addresses the lack of capacity in local knowledge management systems, and can help illuminate pathways to sustainability. In an era in which society is seeking to transition to clean energy and sustainable economic growth, knowledge of the pathways to these futures is needed, along with showcases demonstrating that such change is possible. At least initially, examples are more likely to come from islands and cities than large regions and countries. Islands are disproportionately affected by global change and epitomize the coastal zones where most of humanity lives. They serve as models for continental regions and, ultimately, for our common island home: planet Earth.

Abbreviations

CRIOBE: Centre de Recherches Insulaires et Observatoire de l’Environnement (Center for Island Research and Environmental Observatory); GEO: Group on earth observations; GEOSS: Global Earth Observation System of Systems; IDEA: Island Digital Ecosystem Avatars; IPBES: International panel on biodiversity and ecosystem services; LTER: Long Term Ecological Research.

Competing interests

The authors declare that they have no competing interests.

Authors’ contributions

ND drafted the original text with DF, DG, SH, SP and MT (representing the five founding institutions of the IDEA Consortium). Other co-authors contributed to the text and/or participated in Consortium workshops that developed the concepts presented here. J LH developed the first draft of Fig. 1. A full list of IDEA Consortium members supporting the concepts described herein can be found on the Moorea IDEA website [27]. All authors read and approved the final manuscript.

Funding

This paper is a contribution of CRIOBE and the Gump South Pacific Research Station (#213). Work was supported in part by: the Institute of Theoretical Physics and the Pauli Center at ETH Zurich; the US National Science Foundation (NSF Moorea Coral Reef Long Term Ecological Research Site, OCE-1236905; Socio-Ecosystem Dynamics of Natural-Human Networks on Model Islands, CNH-1313830; Coastal SEES: Adaptive Capacity, Resilience, and Coral Reef State Shifts in Social-ecological Systems, OCE-1325652, OCE-1325554); the Gordon and Betty Moore Foundation (Berkeley Initiative in Global Change Biology; Genomic Standards Consortium); Courtney Ross and the Ross Institute; UC Berkeley Vice Chancellor for Research; CRIOBE; and the France Berkeley Fund (FBF 2014-0015).

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Table 1 Research priorities of the IDEA Consortium

Working group	Task
1. Data science	Integrating diverse data sources, coupling models, and visualizing information
2. Physical modeling	Oceanic and atmospheric forcing, and physical-chemical properties and fluxes
3. Genes to ecosystems	Biodiversity dynamics, evolutionary processes, and ecological interactions
4. Social-ecological systems	Coupling past, present, and future ecosystems to human activities
5. Simulations, synthesis, and service	Use-oriented avatar as a platform for data exploration, scenario-based planning, and education

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8. Soranno PA, Bissell EG, Cheruvellil KS, Christel ST, Collins SM, Fergus CE, et al. Building a multi-scaled geospatial temporal ecology database from disparate data sources: fostering open science and data reuse. *Gigascience* 2015; 4:28.
 9. Purves D, Scharlemann J, Harfoot M, Newbold T, Tittensor DP, Hutton J, et al. Ecosystems: time to model all life on Earth. *Nature*. 2013;493:295–7.
 10. GEO: Global Earth Observation System of Systems GEOSS. 10-year implementation plan reference document. 2005th ed. Noordwijk: ESA Publications Division; 2005.
 11. International Council for Science. Future Earth – 2025 vision. Paris: Future Earth – Interim Secretariat; 2014.
 12. Cressey D. Tropical paradise inspires virtual ecology lab. *Nature*. 2015;517:255–6. CRIOBE. <http://www.criobe.pf/>.
 13. Gump South Pacific Research Station. <http://www.moorea.berkeley.edu/>.
 15. LABEX CORAIL <http://www.labex-coral.fr>.
 16. Moorea Coral Reef Long Term Ecological Research site <http://mcr.lternet.edu>.
 17. Moorea Biocode Project <http://mooreabiocode.org>.
 18. Check E. Treasure island: pinning down a model ecosystem. *Nature*. 2006; 439:378–9.
 19. McCliment EA, Nelson CE, Carlson CA, Alldredge AL, Witting J, Amaral-Zettler LA. An all-taxon microbial inventory of the Moorea coral reef ecosystem. *ISME J*. 2012;6:309–19.
 20. Adam TC, Schmitt RJ, Holbrook SJ, Brooks AJ, Edmunds PJ, Carpenter RC, et al. Herbivory, connectivity, and ecosystem resilience: response of a coral reef to a large-scale perturbation. *PLoS One*. 2011;6:e23717.
 21. Kirch PV. On the road of the winds: an archaeological history of the Pacific Islands before European contact. Berkeley (California, USA): University of California Press; 2002.
 22. Clark WC. Sustainability science: a room of its own. *Proc Natl Acad Sci U S A*. 2007;104:1737–8.
 23. Hood L, Heath JR, Phelps ME, Lin B. Systems biology and new technologies enable predictive and preventative medicine. *Science*. 2004;306:640–3.
 24. Clark WC, Tomich TP, van Noordwijk M, Guston D, Catacutan D, Dickson NM, et al. Knowledge systems for sustainable development special feature Sackler Colloquium: boundary work for sustainable development: natural resource management at the Consultative Group on International Agricultural Research (CGIAR). *Proc Natl Acad Sci USA* 2011; published ahead of print August 15, 2011, doi:10.1073/pnas.0900231108.
 25. Larigauderie A. The Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES): a call to action. *GAIA Ecol Perspect Sci Soc*. 2015;24:73–3.
 26. McInerney GJ, Chen M, Freeman R, Gavaghan D, Meyer M, Rowland F, et al. Information visualisation for science and policy: engaging users and avoiding bias. *Trends Ecol Evol*. 2014;29:148–57.
 27. IDEA Consortium members. <http://mooreaidea.org/participants>.

Received: 12 December 2015 Accepted: 21 February 2016

References

1. National Research Council. Convergence: facilitating transdisciplinary integration of life sciences, physical sciences, engineering, and beyond. Washington DC: The National Academies Press; 2014.
2. Mace G. Ecology must evolve. *Nature*. 2013;503:191–2.
3. Duraipah AK, Rogers D. The Intergovernmental Platform on Biodiversity and Ecosystem Services: opportunities for the social sciences. *Innovation: The European Journal of Social Science Research* 2011;24:217–224.
4. Karr JR, Sanghvi JC, Macklin DN, Gutschow MV, Jacobs JM, Bolival B, et al. A whole-cell computational model predicts phenotype from genotype. *Cell*. 2012;150:389–401.
5. Vitousek PM. Oceanic islands as model systems for ecological studies. *J Biogeogr*. 2002;29:573–82.
6. Future Cities Laboratory. <http://www.fcl.ethz.ch>.
7. Center for Urban Science and Progress. <http://cusp.nyu.edu>.

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